Title of Investigation:

The Gated Electrostatic Mass Spectrometer (GEMS)

Principal Investigator:

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Initiation Year:

FY 2005

Aggregate Amount of Funding Authorized in FY 2005 and Earlier Years:

$55,000

Funding Authorized for FY 2006:

$16,000

Actual or Expected Expenditure of FY 2006 Funding:

In-house: $16,000

Status of Investigation at End of FY 2006:

To continue as outlined below; completion set for the end of FY 2006

Expected Completion Date:

September 2006

Purpose of Investigation:

A mass spectrometer finds the mass and charge of ions (atoms missing one or more electrons) that flow through it. The goal of this investigation is to develop a mass spectrometer that offers a large-aperture area per unit mass and power and works only with electrical fields. This will enable unique opportunities in lunar exploration and in Ionosphere-Thermosphere-Magnetosphere science. The lack of such an instrument currently restricts the scope of investigations open to NASA. This includes everything from exploration enterprise missions to map the lunar surface to science missions to learn more about the ionosphere, thermosphere and magnetosphere, and the composition of comets. For example, to measure the mineral composition of the lunar surface, scientists would need a very large mass spectrometer—the equivalent of about 1,000 conventional mass spectrometers operating simultaneously.

The proposed gated electrostatic mass spectrometer (GEMS) uses a simple parallel plate, electrostatic field deflector in which all ions of a selected energy follow the same trajectory independent of ionic mass. The electrostatic field is gated "on" and "off" by a low voltage (1 to 5 volts) so that it remains "on" for one microsecond or more and "off" for a fraction of a microsecond. Ions inside the deflector at gate onset do not undergo the full deflection, cannot exit the deflector, and do not reach the detector. Of the ions near the deflector entrance at gate onset, the lightest ions (H^+) reach the detector first, followed by heavier ions, each arriving at a time $t=x\sqrt{m/2E}$ after gate onset (x is the length of the deflector cavity, m the ionic mass and E the ion energy). Within the open gate period (> 1 microsecond), ions initially outside the deflector will pass and reach the detector because they will undergo full deflection once they reach the interior of the deflector. Since the ionic masses are randomly arranged in space, the addition of many successive gate periods will yield an integrated spectrum as shown in Figure 1.

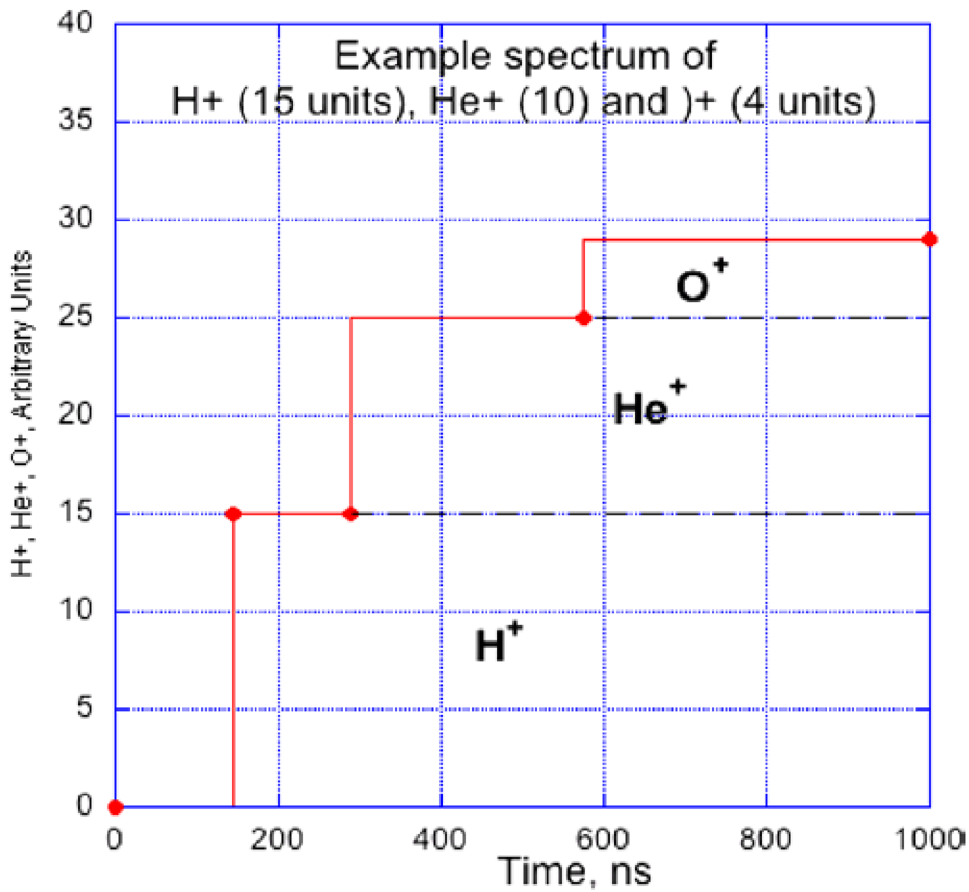

Figure 1. Integrated time simulated for a GEMS with electrostatic deflector operating at an energy of 25 eV and a deflector length of 1 cm. The H^+, He^+, and O^+ ions that were at the deflector entrance at gate onset arrive respectively at the times when the red line goes vertical. 25 eV ions of different masses up to about 170 atomic mass units (AMU) may be separated in 2 microseconds in this GEMS cavity.

An immediate advantage of GEMS is that the entrance aperture is a long slit, increasing the sensitive area per spectrometer by a factor of 10. Another factor of 5 to 10 follows from the ability to easily make an array of mass spectrometers and thereby increase the total aperture area. Because of their simple rectangular shapes, the new spectrometers may be stacked side-by-side to build up arrays that make the 10 cm^2 aperture a reality. This simple shape is due to the small deflections in ion trajectories obtained inside the parallel plate deflectors of Goddard's Small Deflection electrostatic Energy Analyzer (SDEA), which provides the basis for the GEMS design.

In the integrating mode of operation shown in Figure 1, a timing circuit with N registers performs the task of storing the number of particles arriving at each one of N consecutive time intervals. The same circuit controls the time-gated deflection voltage. The number of time intervals N will determine the mass resolution—ultimately limited by the energy resolution of the SDEA. The integrating mode is suitable for applications in which the ion flux and composition may be assumed to be constant while 10^4 ions or more are accumulated. This condition is easily met in most applications.

We also will pursue a second mode of operation with the same GEMS sensor, using an electrostatic beam sweep just ahead of the entrance slit. In this mode, GEMS behaves as a conventional time-of-flight (CTOF) spectrometer, but with a feature that may use a relatively small number N of time intervals and registers ($N \approx 10$) to resolve two species with small mass difference (0.1 AMU or less) in real time. The TOF spectrum operating in the second mode corresponds to the time-derivative of the integral spectrum operating in the first mode. The second mode will suffer from low duty cycle and lower sensitivity as in most conventional TOF spectrometers; however, it will still be a novel contribution because it is miniaturized, and is providing high-mass resolution in a very small package.

Accomplishments to Date:

The ion source that will operate at the front end of the spectrometer has been designed, fabricated, and tested. Figure 2 shows the actual ion source and Figure 3 the data obtained with the ultra-low power thermionic cathode, demonstrating that the ion source yields an electron-beam current of about 1 mA. Total power is about 80 mWatts. This is very close to the minimum power required in a field-emission cathode, about 50 mWatts. The spectrometer's ion source is an essential element to enable neutral composition measurements. With the ion source defined, it was then possible to determine the GEMS geometry and to design the GEMS spectrometer stage, now under construction.

Another issue that we needed to resolve before finalizing the design was optimizing GEM's duty cycle. Simulations show that it is possible to sweep out the ions remaining in the deflector after the gate is turned off. This is best achieved with high voltage (20 to 100 V) applied to the deflector plates during the off period, a time shorter than the gate period. Fortunately, the SDEA can provide 25 eV ion transmission with 5 V applied to the deflector plates. Therefore, a voltage of 20 to 100 V applied during the off period, a fraction of a microsecond, may achieve effective sweep out of the ions before the next gate onset. The circuit for the sweep-out feature is new and will be designed in by March 2006.

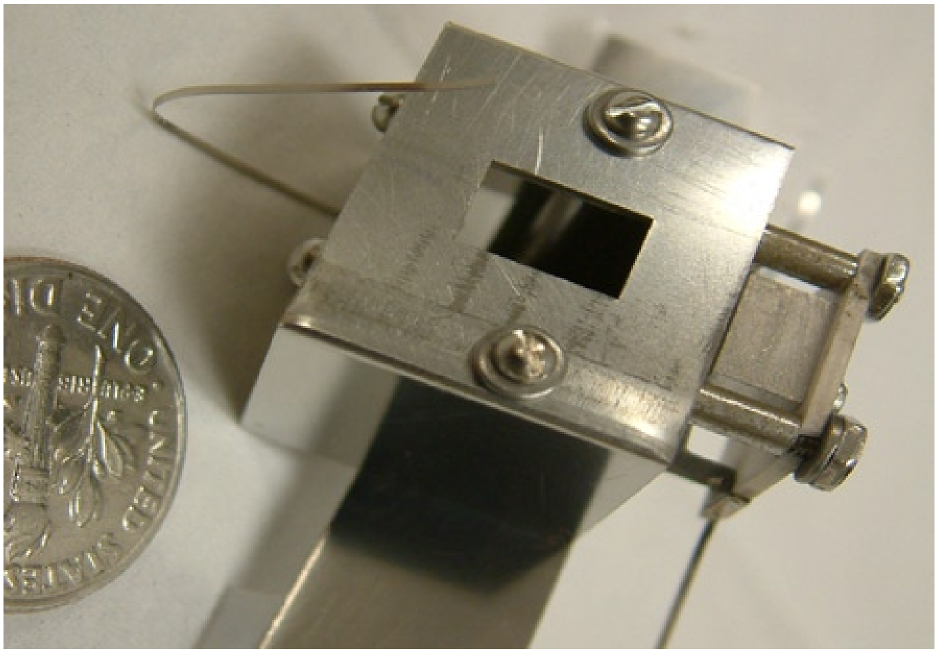

Figure 2. Ion source assembly showing the cathode connections on the right-hand side and the repeller connection on the metal ribbon. The rectangular aperture allows for the passage of the neutral stream, which is ionized by electron impact just beneath it. Acceleration electrodes to inject the resulting ion into the GEMS are not shown since they form part of the GEMS geometry.

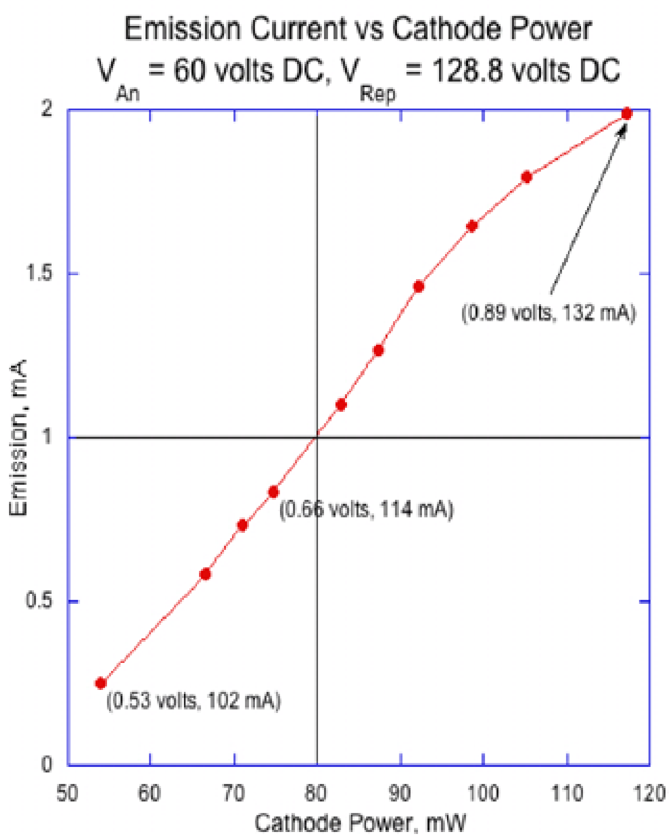

Figure 3. Cathode test data; see text for discussion.

Publications and Conference Presentations:

Herrero, Grebowsky, Leitner and, Matsumura, "Multi-point measurements in the ionosphere-thermosphere system enabled by the Small Deflection Energy Analyzer (SDEA)," Spring AGU Meeting, New Orleans, La., May 2005.

Planned Future Work:

1. Fabrication and test of GEMS unit with and without ion source, operating in integrating mode
2. Design, fabrication, and test of CTOF (second mode) mode of operation
3. Optimal selection of sweep-out voltage and electronics design for fast power supply with more than 100 V/ms slope
4. Optimization of the ion source for incremental reduction of power

Key Points Summary:

Project's innovative features: The project's innovative features include: (1) first mass spectrometer using purely electrostatic fields; 2) fast electronic gating circuits with memory registers to enable the acquisition of integrated and differential mass spectra; 3) push Goddard's state of expertise in ASICs with large numbers of registers (N = 100 to 1000); and 4) increase available mass spectrometer aperture (sensitivity) by more than 2 orders of magnitude.

Potential payoff to Goddard/NASA: Dramatic increase in sensitivity per instrument mass for very large-aperture (>10 cm^2) applications or conventional apertures (10^{-2} cm^2 in less than 300g/200mW). Will enable acquisition of lunar surface composition maps with a very large-aperture mass spectrometer: 10 cm^2 aperture on a flat instrument roughly 3x20x20 cm^3, consuming less than 20 W. Will enable multi-point measurements with nanosats in future LWS and Explorers investigations of the Ionosphere-Thermosphere-Magnetosphere with a compact mass spectrometer with total mass/power less than 300 g/1W—mass/power based on Falcon-Sat 3 and NRL's ANDE satellite SDEA prototypes.

The criteria for success: The project will be considered a success when we demonstrate a mass spectrum with the prototype GEMS in the laboratory in either an integrating or differential mode of operation.

Technical risk factors: No mass spectrometer capable of an aperture greater than 1cm^2 has ever been demonstrated. The electronic circuit presents a high risk and is the most challenging part of the project. Our approach will be to adopt commercial-off-the-shelf (COTS) ICs to implement at least 20 registers in our PCB circuit and investigate the implementation in the ASIC format. Another challenge is presented by the timing interval. For the 1 cm GEMS, an interval of 1 ns is desirable to achieve mass resolution of about 300—our goal for lunar exploration. In our prototype test, we will investigate the feasibility of this goal in the ASIC format, but work with a nominal 10 ns interval in our COTS circuit.